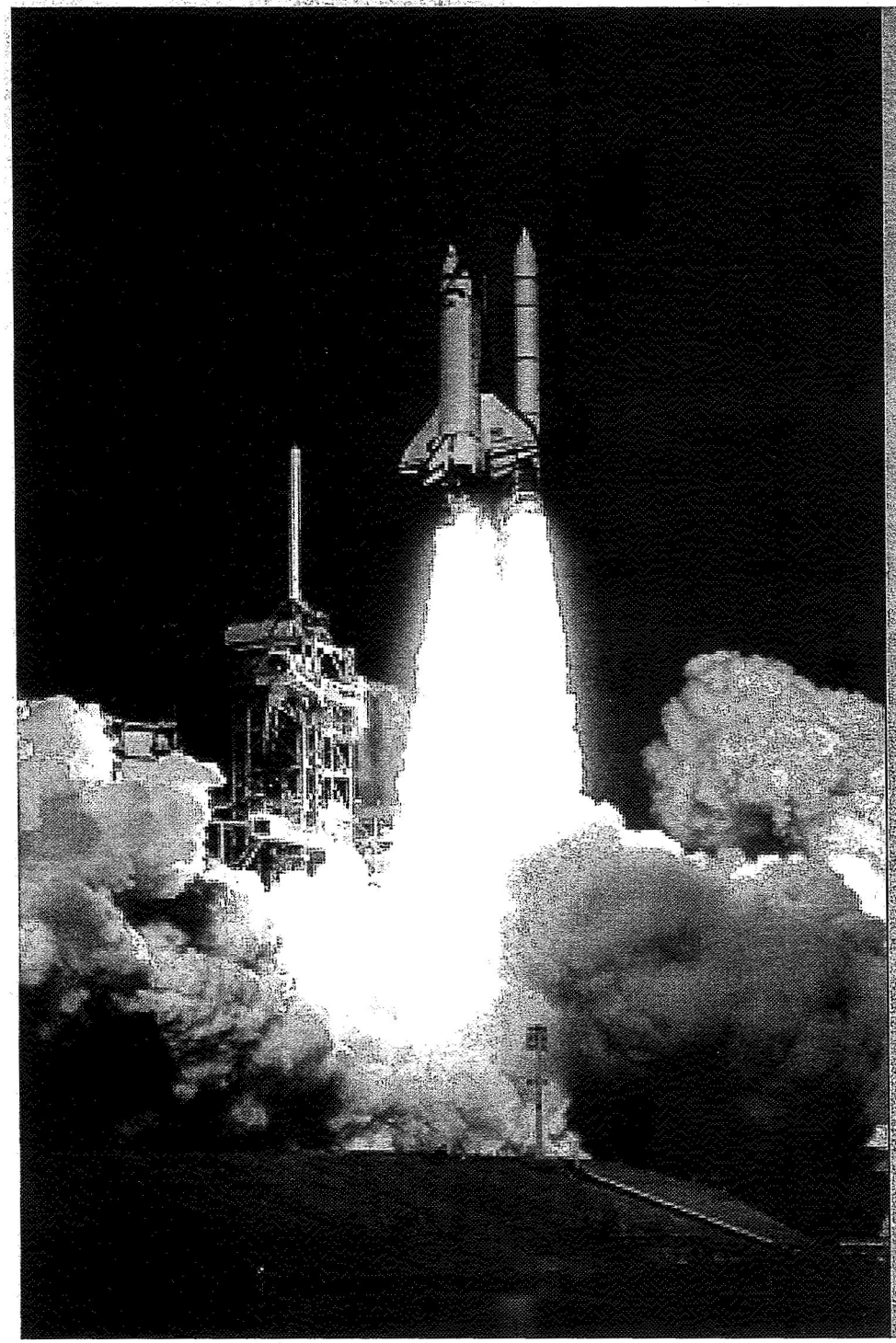
Name: Michael U. Rudolphi
Title: Recovery of Space Shuttle *Columbia* and Return to Flight of Space Shuttle Discovery
Organization: NASA
Email: Mike.Rudolphi@nasa.gov
Phone: 256-544-0202
Degrees: BS and MS, Civil Engineering, University of Tennessee
Position: Director, Engineering Directorate, Marshall Space Flight Center

NASA has come a long way in our journey to reduce the risks of operating the Space Shuttle system. The External Tank bipod Thermal Protection System has been redesigned to eliminate the proximate cause of the *Columbia* accident. In all areas, we have applied the collective knowledge and capabilities of our Nation to comply with the *Columbia* Accident Investigation Board recommendations and to raise the bar beyond that. We have taken prudent technical action on potential threats to review and verify the material condition of all critical areas where failure could result in catastrophic loss of the crew and vehicle. We are satisfied that critical systems and elements should operate as intended—safely and reliably. While we will never eliminate all the risks from our human space flight programs, we have eliminated those we can and reduced, controlled, and/or mitigated others. The remaining identified risks will be evaluated for acceptance. Our risk reduction approach has its roots in the system safety engineering hierarchy for hazard abatement long employed in aerospace systems engineering. The components of the hierarchy are, in order of precedence, to: design/redesign; eliminate the hazard/risk; reduce the hazard/risk; and control the hazard/risk and/or mitigate the consequence of the remaining hazard/risk through warning devices, special procedures/capabilities, and/or training. This proven approach to risk reduction has been applied to potential hazards and risks in all critical areas of the Space Shuttle and has guided us through the technical challenges, failures, and successes present in return to flight endeavors. This approach provides the structured deliberation process required to verify and form the foundation for accepting any residual risk across the entire Space Shuttle Program by NASA leadership.



Recovery of Space Shuttle *Columbia*

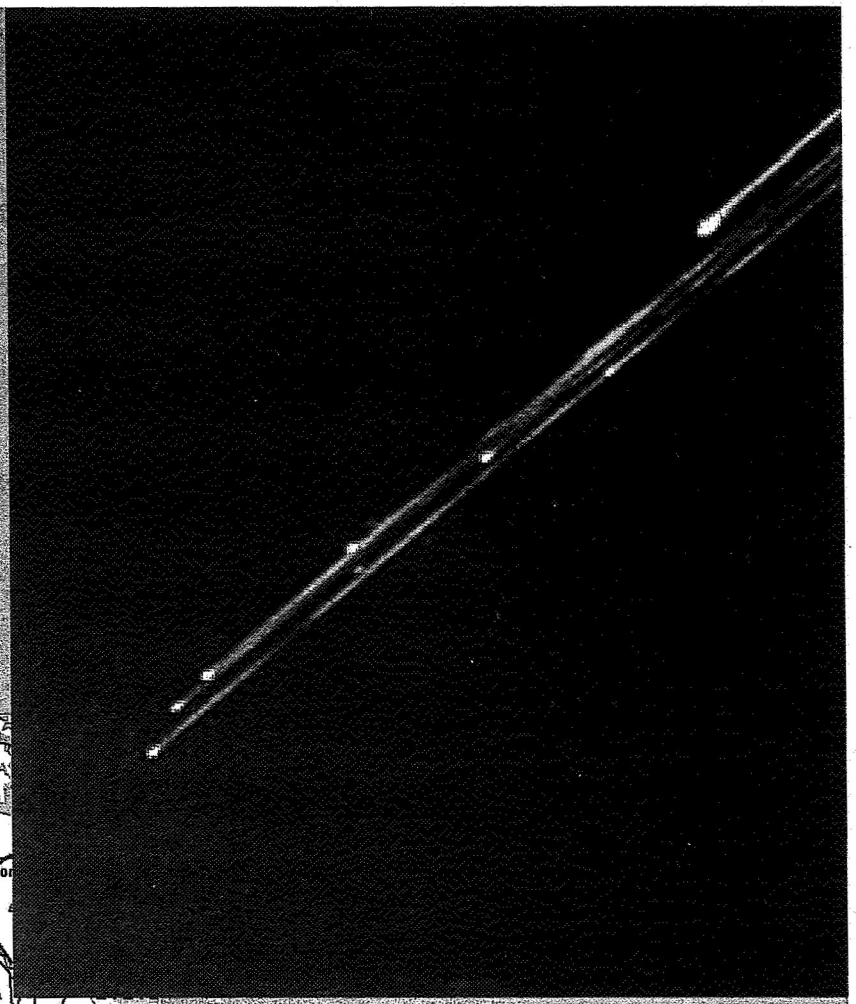
and

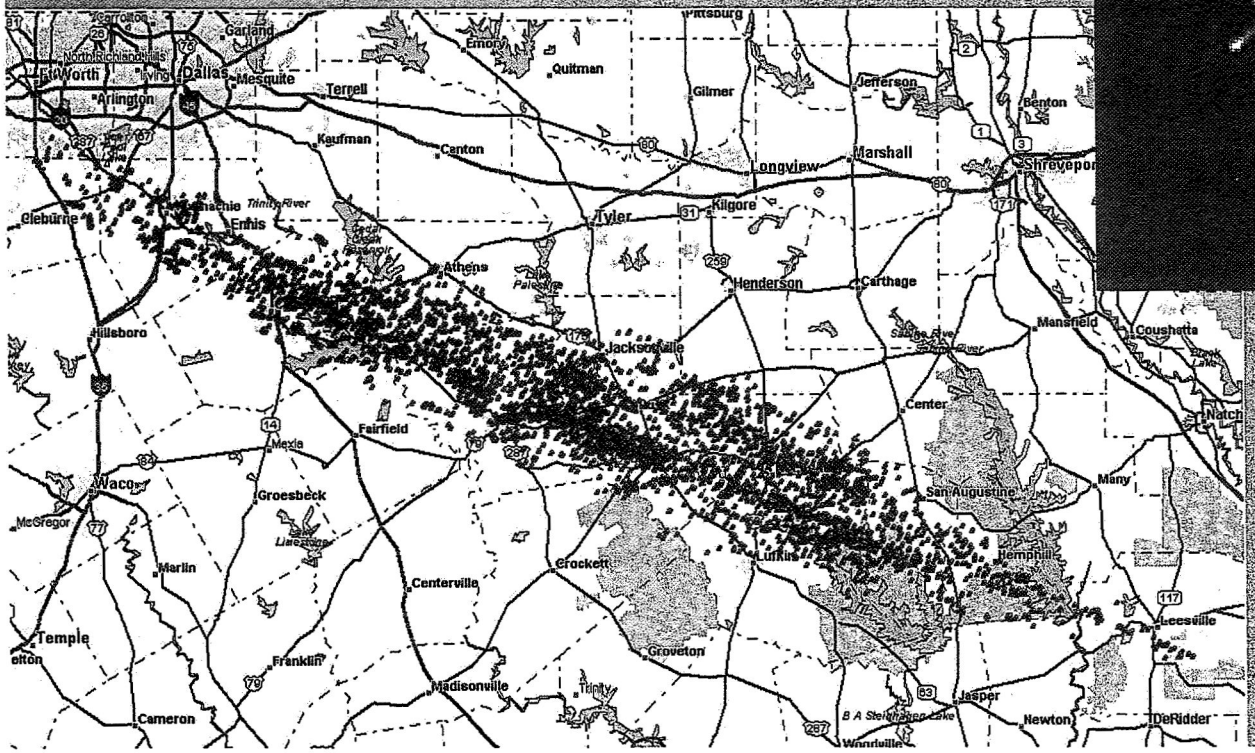
Return to Flight of Space Shuttle *Discovery*

Michael U. Rudolphi
Engineering Director
Marshall Space Flight Center

On February 1, 2003, Space Shuttle *Columbia* and her crew were lost upon re-entry during STS-107.

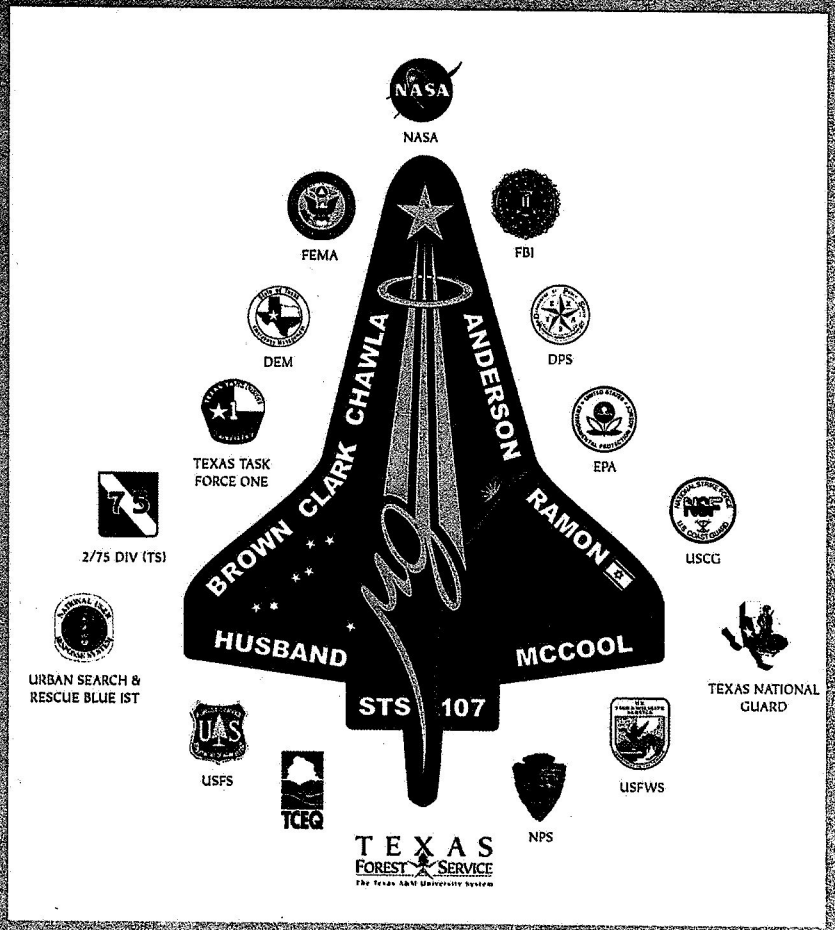
The debris field ranged from eastern Texas to western Louisiana.



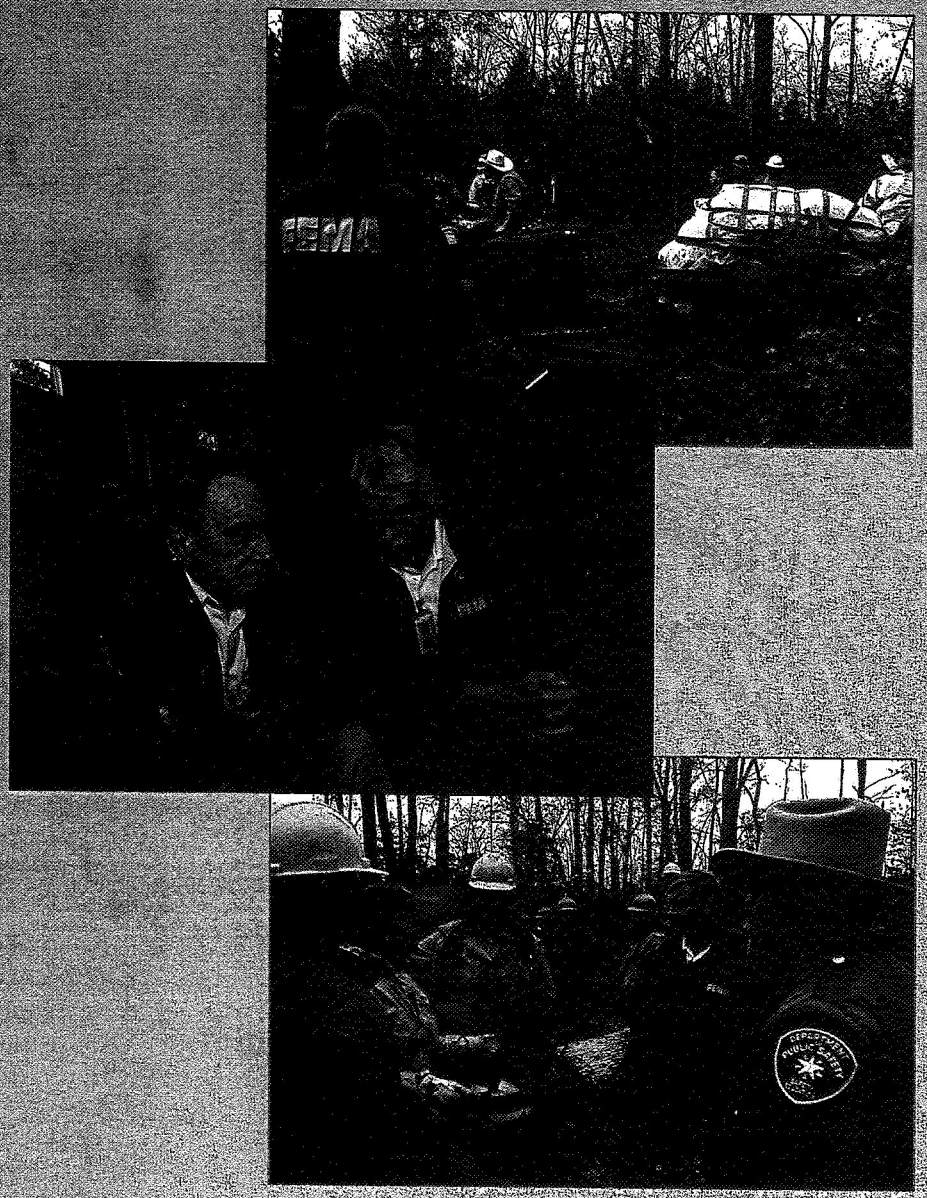


Radar - derived debris plot

Multi-Agency response to a monumental challenge

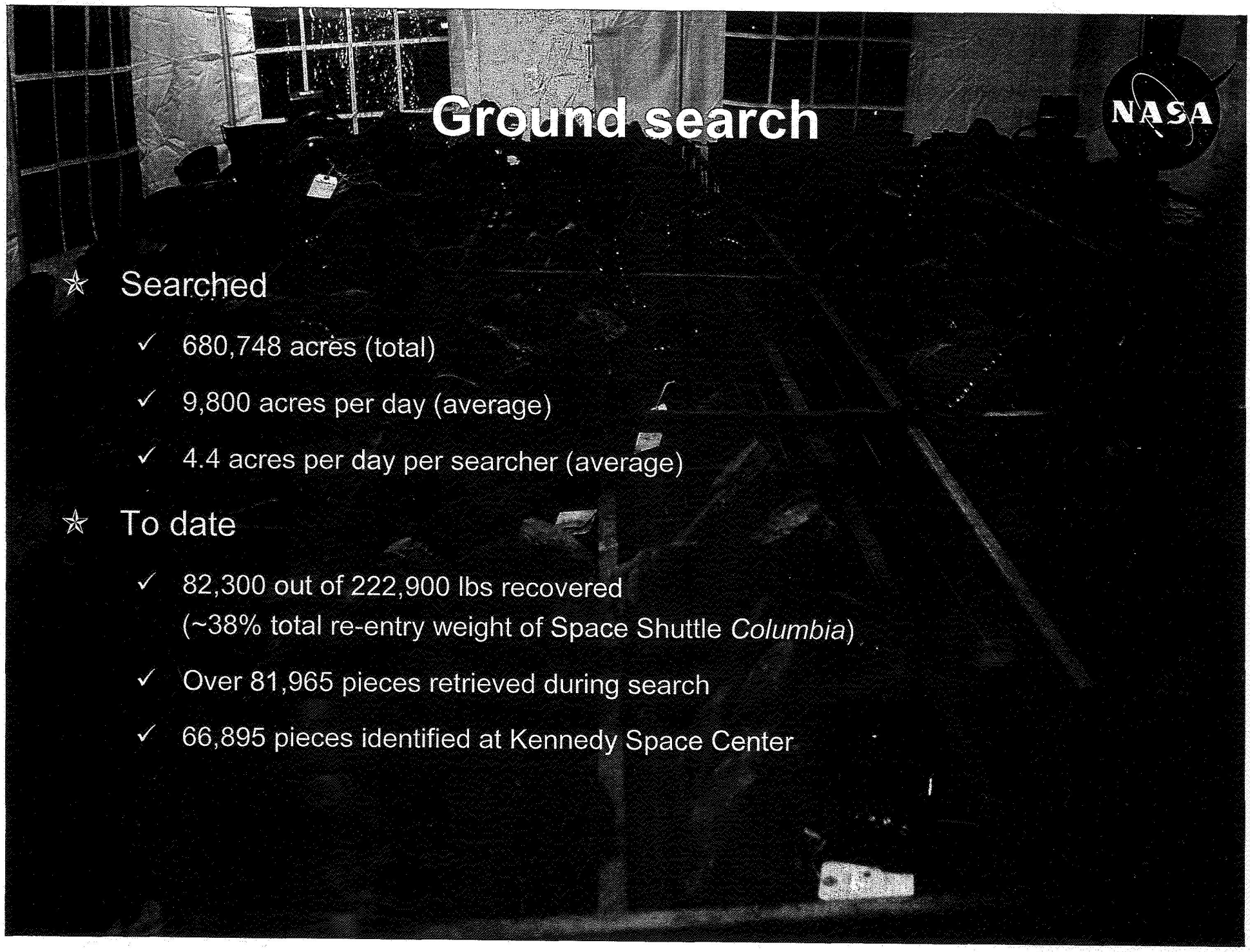


- Disaster field offices (DFO's) were established at Barksdale AFB, LA and Lufkin and Ft. Worth, TX.
- More than 25,000 people were actively involved in search efforts. Over 480 Federal, state, and local agencies (as well as private organizations and volunteer groups) provided search personnel, supplies, and equipment.
- Debris field included:
  - ✓ Area about the size of Rhode Island
  - ✓ Main corridor ~10 miles wide and 240 miles long, stretching from Dallas, TX to Fort Polk, LA
  - ✓ 8 counties inhabited by over 400,000 people (none injured by falling debris)



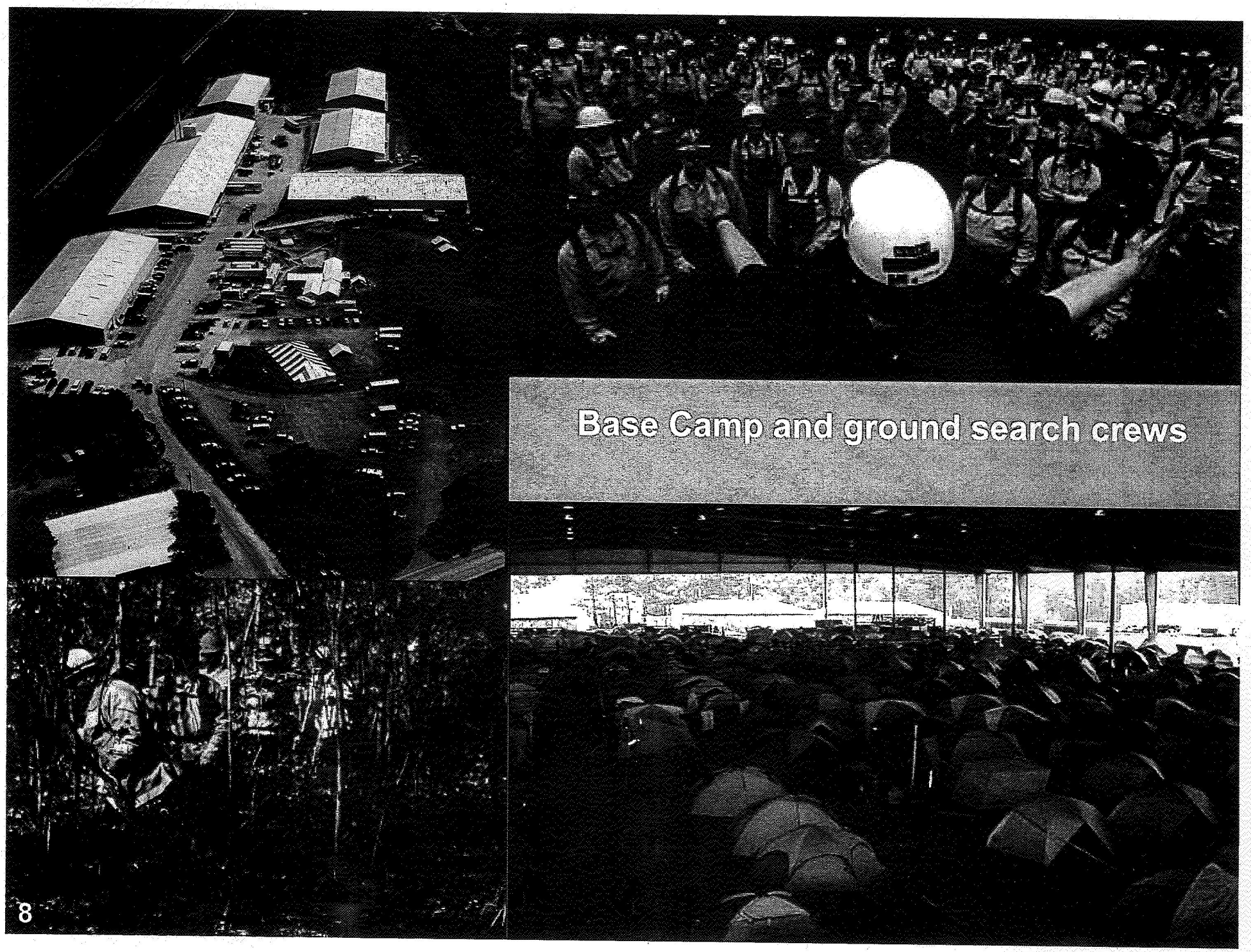
Goals

- ☆ Ensure public safety.
- ☆ Recover crew.
- ☆ Retrieve evidence.
- ☆ Compensate costs incurred by local jurisdictions.



Ground search

- Searched
  - ✓ 680,748 acres (total)
  - ✓ 9,800 acres per day (average)
  - ✓ 4.4 acres per day per searcher (average)
- To date
  - ✓ 82,300 out of 222,900 lbs recovered
    (~38% total re-entry weight of Space Shuttle *Columbia*)
  - ✓ Over 81,965 pieces retrieved during search
  - ✓ 66,895 pieces identified at Kennedy Space Center



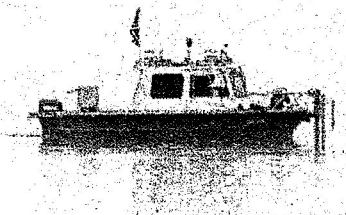
Base Camp and ground search crews

Water Search

- ✯Dive Teams
  - ✓ US Navy Salvage Team
  - ✓ US Coast Guard Team
  - ✓ FBI Dive Team
  - ✓ DPS Dive Team
  - ✓ Houston Police Dive Team
  - ✓ Galveston Dive Team

- ✯Boats
  - ✓ 13 dive boats
  - ✓ 12 security boats
  - ✓ 10 sonar boats
- ✯Sonar types used
  - ✓ Multi-beam
  - ✓ Side scan

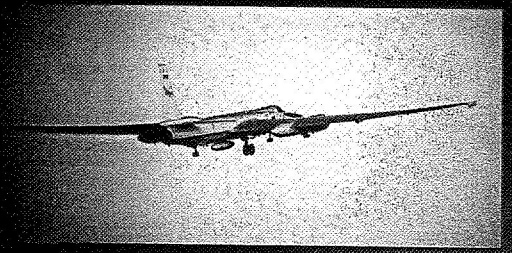
- ✯Total area scanned
  - ✓14.69 sq. miles in Toledo Bend Reservoir
  - ✓3.17 sq. miles in Lake Nacogdoches

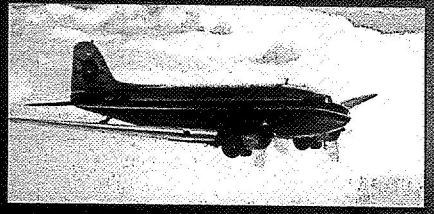


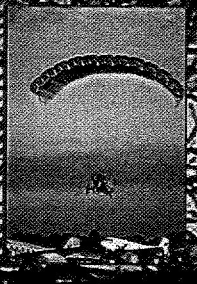
- ✯Dives
  - ✓3,100 targets cleared in Toledo Bend Reservoir
  - ✓365 targets cleared in Lake Nacogdoches
- ✯Personnel involved per day: up to 166
- ✯Bottom time: 800 hours total

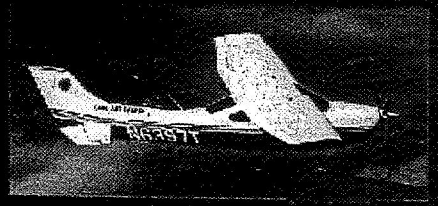
Air search

- Helicopters
- Fixed wing aircraft
- DC-3 aircraft
- Civil Air Patrol
- Department of Defense
- NASA ER-2 (U-2 jet)
- Motorized paragliders





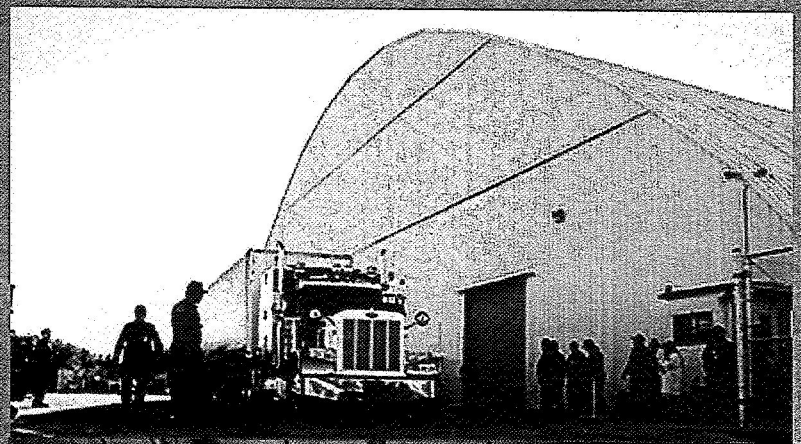




Monomethyl hydrazine spherical tank

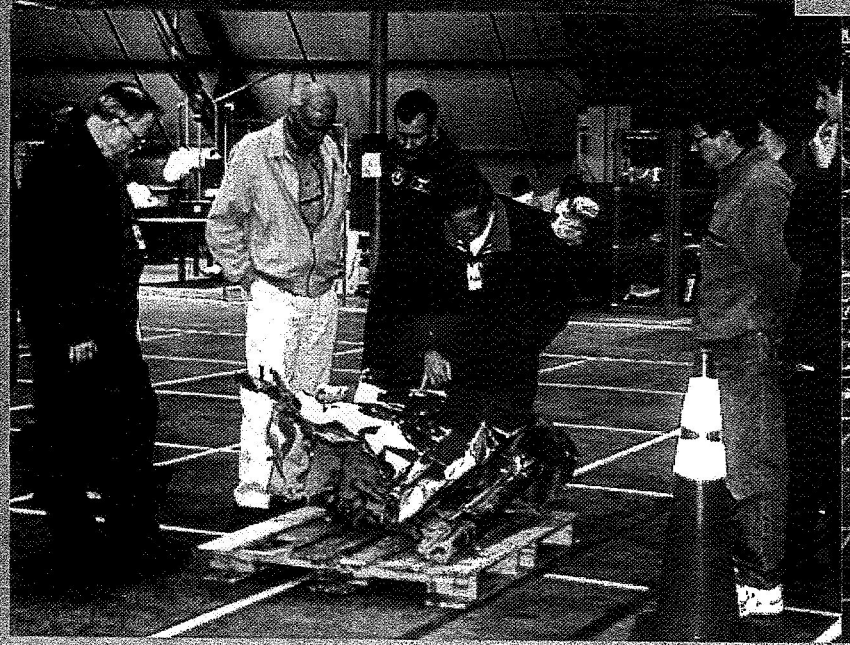
Decontamination setup

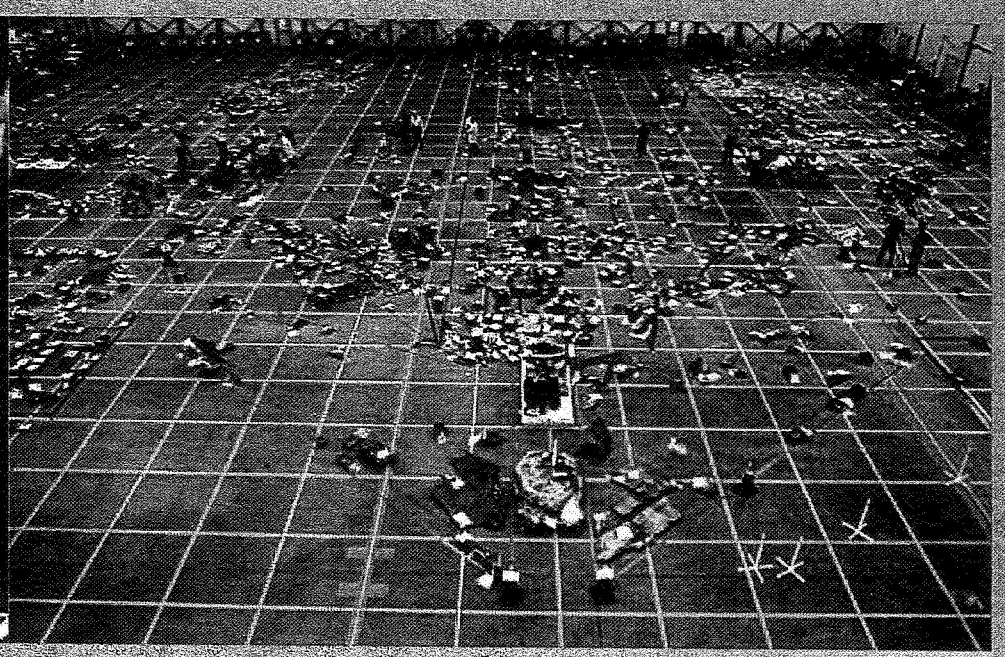
Reassembling the pieces



All retrieved material shipped:

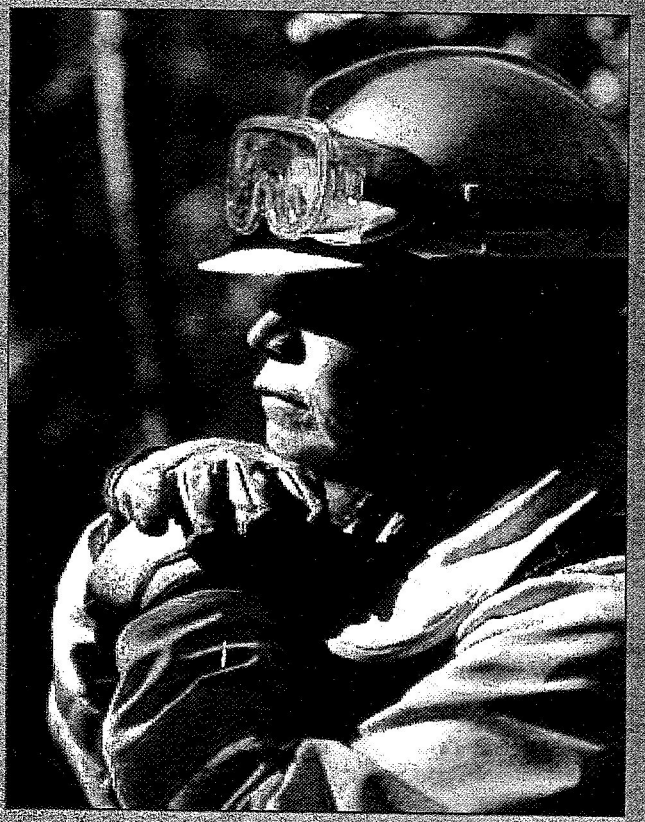
- ☆ first to Barksdale AFB or Johnson Space Center
- ☆ then to Kennedy Space Center





Why *Columbia* recovery succeeded

- High-quality, capable, compatible people
- Clearly articulated missions, strong universal buy-in
- Trust built through transparency of leadership
- Local capability, community generosity
- Powerful support for NASA and the space program
- No ongoing threat to life or property
- Openness of physical space
- Constituent units empowered
- Accountable, but not overly rule-bound
- Negotiated competing missions, lack of "turf" struggles
- Explicit attention to morale



In Memoriam

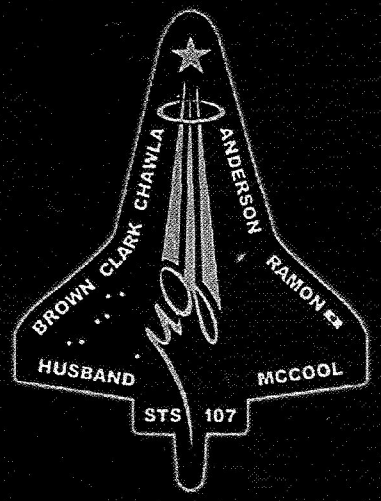
Commander:
Rick Husband

Pilot:
William McCool

Mission specialists:
Mike Anderson
David Brown
Kalpana Chawla
Laurel Clark

Payload specialist:
Ilan Ramon (Israel)

Lost during recovery effort:
Jules "Buzz" Mier, Jr.
Charles Krenek



COLUMBIA
ACCIDENT INVESTIGATION BOARD

REPORT VOLUME I
AUGUST 2003

Return to Flight
Task Group

RTF TG

Final Report
July 2005

NASA

July 28, 2004
Volume 1, Revision 2.1

NASA's Implementation Plan for Space Shuttle Return to Flight and Beyond

A periodically updated document demonstrating our progress toward safe return to flight and implementation of the Columbia Accident Investigation Board recommendations

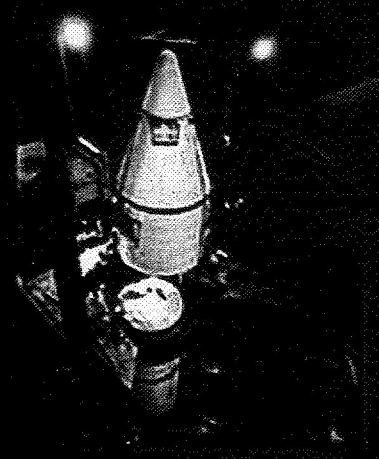
NASA

Report of the
President's Commission on Implementation of United States Space Exploration Policy

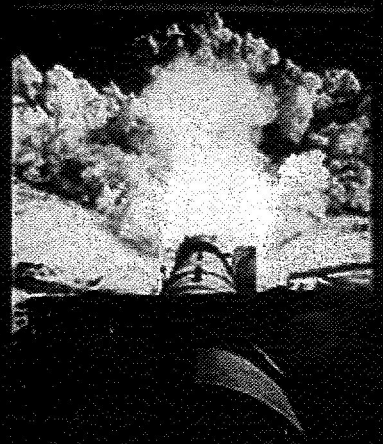
A Journey to Inspire, Innovate, and Discover

June 2004

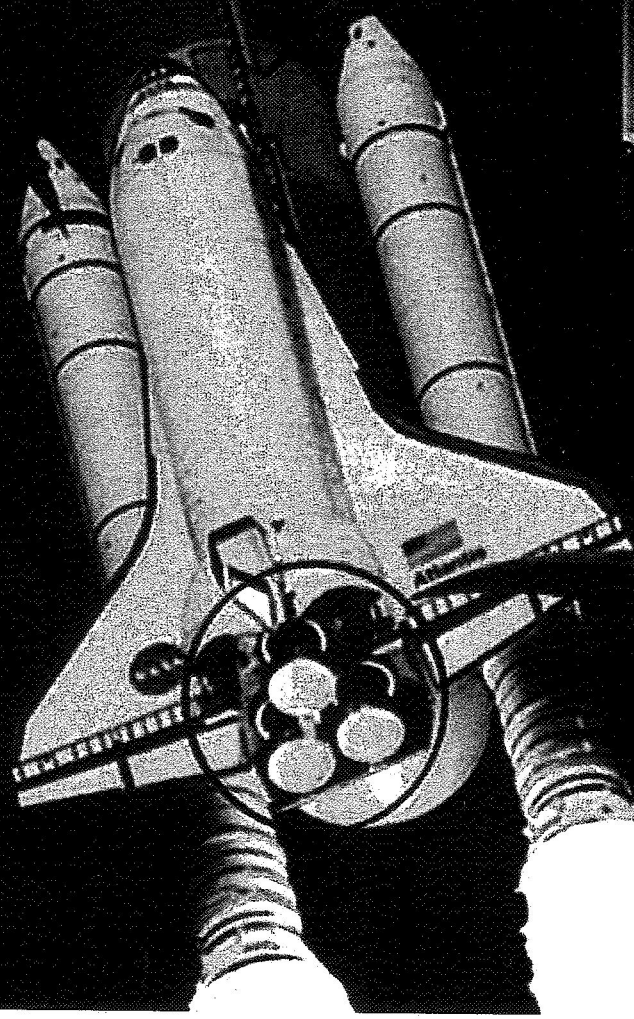
Return to Flight

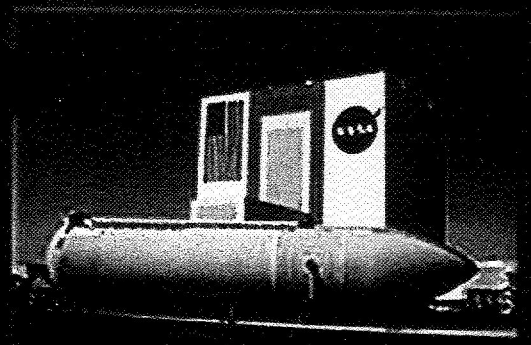


Reusable Solid Rocket Booster



Reusable Solid Rocket Motor

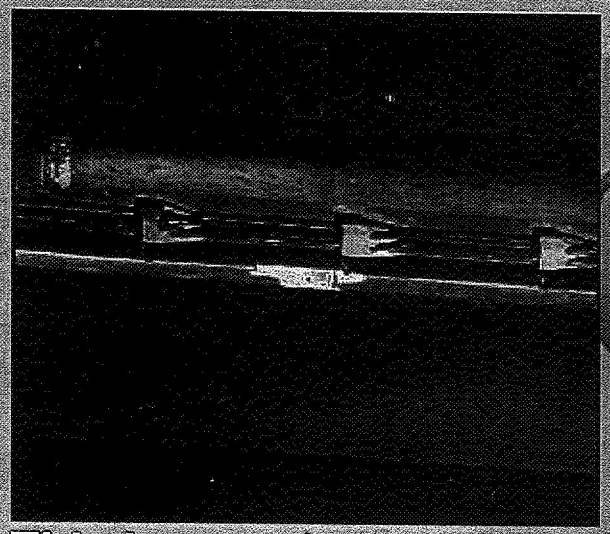




External Tank

Space Shuttle Main Engine

ET/TPS Return to Flight - Development



This image shows a large piece of foam that separated from the ET during STS-114.

nel J Pre-Test

Cryoingestion-Critical Defect Determination

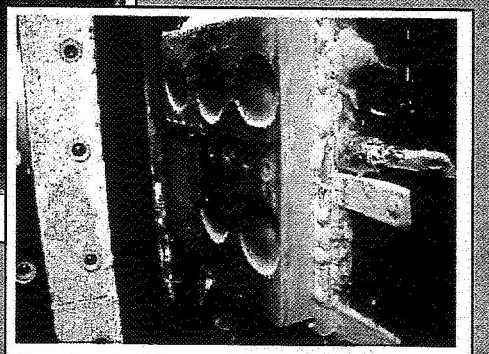
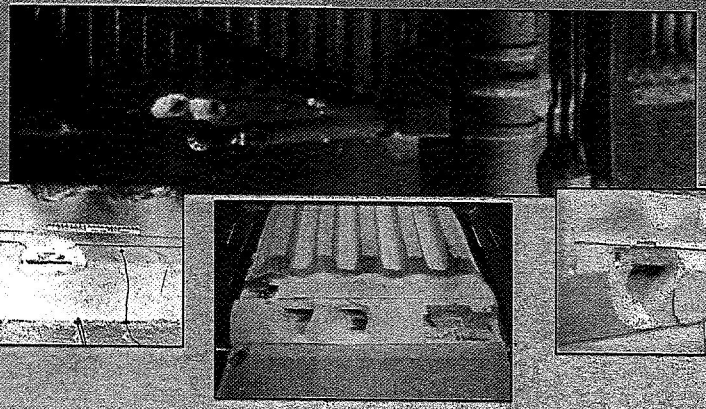
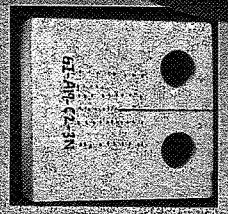


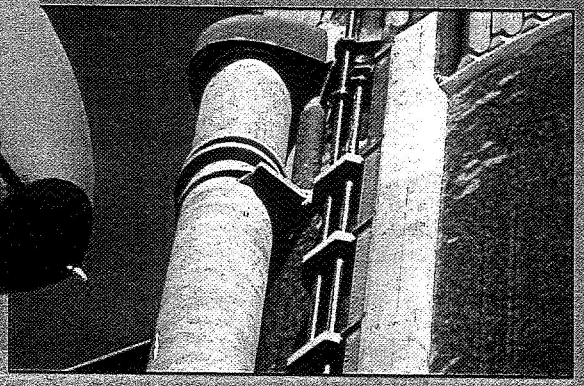
Figure 9.13. Panel J Post-Test 08/27/04



Root Cause Testing

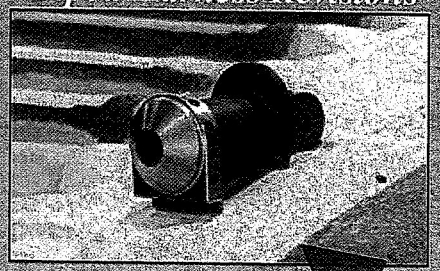


TPS Fracture Toughness

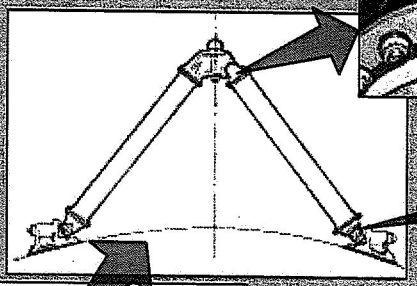


Bellows Ice Mitigation

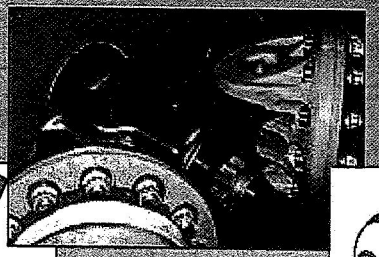
STS-121 / ET-119
Return to Flight Modifications

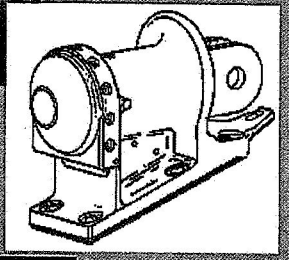


Bipod Harness Revisions

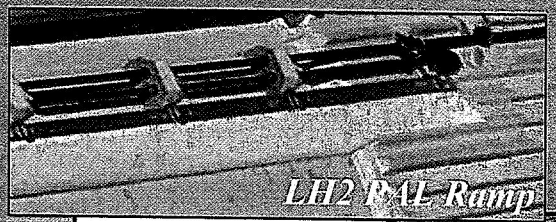


Bipod Hardware Revisions

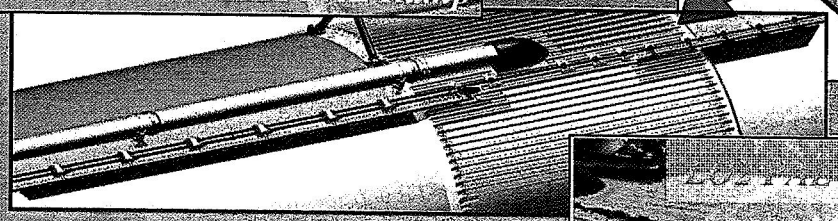


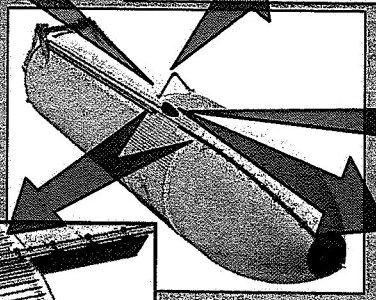


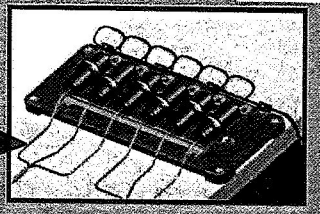
LO2 and LH2 PAL Ramp Elimination



LH2 PAL Ramp

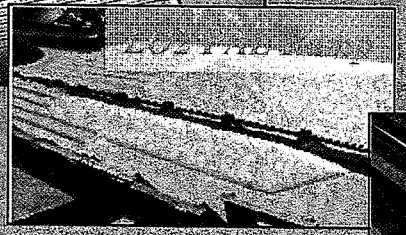


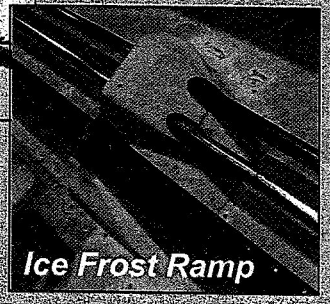




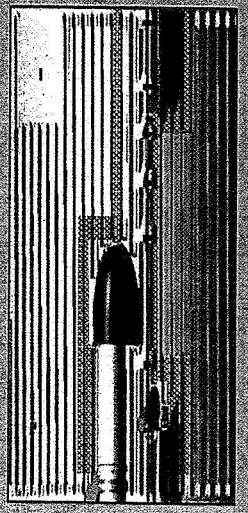
Development Flight Instrumentation

Intertank Acreage Machining / Venting

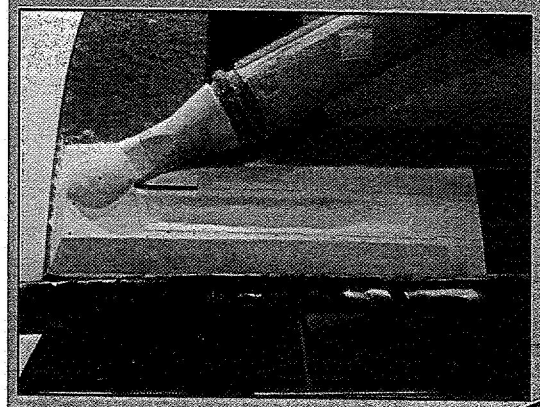




Ice Frost Ramp

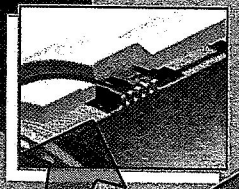


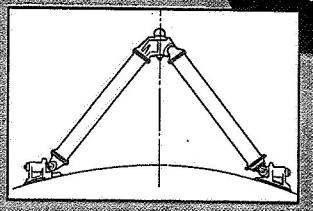
STS-114 / ET-121
Return to Flight Modifications



Remove/ Replace Longeron Closeouts

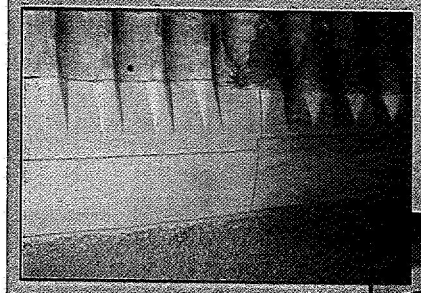
*LO2 Feedline Bellows TPS Drip Lip and * Fwd Bellows Heater System*



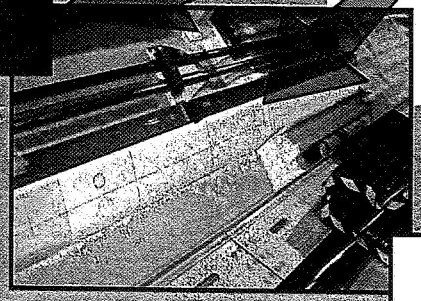


Bipod Strut Hardware (Lubricated thru-bolts)

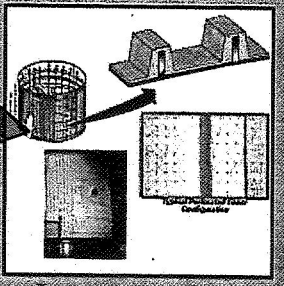
Redesigned Bipod Fitting



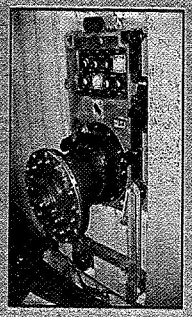
Intertank / LH2 Tank Flange Closeout Enhancement



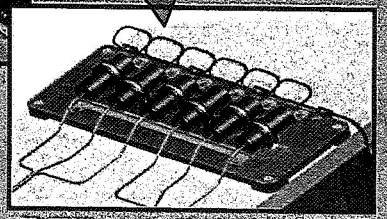
Partial LH2 PAL Ramp Replacement



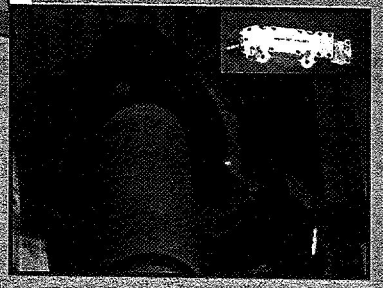
Increase Area of Vented Intertank TPS



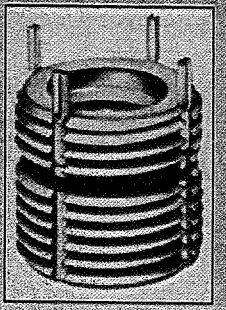
ET Ground Umbilical Redesign



RTF Instrumentation



ET Camera in LO2 Feedline Fairing

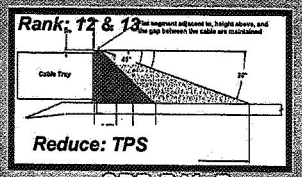


ET/SRB Bolt Catcher Inserts

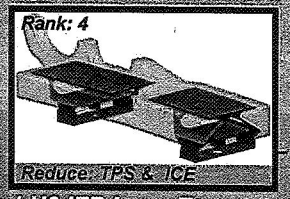
** Delta from RTF Baseline – Not reviewed at SSP DCR*

ET – Future Risk Reduction Redesign Initiatives

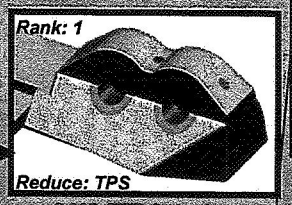
STS: Launch Order	External Tank: Delivery Order
STS 116	ET-123
STS 117	ET-124
STS 118	ET-117
STS 120	ET-120
STS 122	ET-125
STS 123	ET-126
STS 124	ET-128
STS 125	ET-129
STS 119	ET-127
STS 126	ET-130
STS 127	ET-131
STS 128	ET-132
STS 129	ET-133
STS 130	ET-134
STS 131	ET-135
STS 132	ET-136
STS 133	ET-137



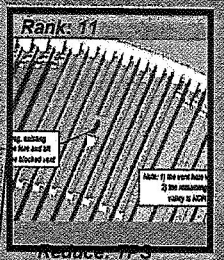
SRB PAL Ramp (ET-126 & 128)



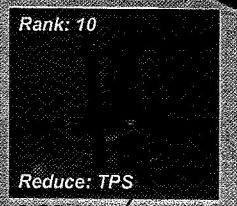
LH2 IFR Long Term (ET-128)



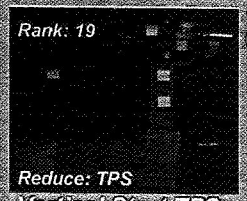
LH2 IFR Interim (ET-124)



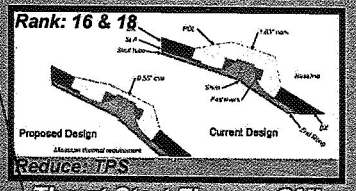
+Z Aerovent (ET-125)



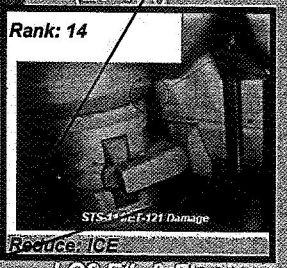
LO2 / Intertank IFR (ET-131)



Vertical Strut TPS (ET-132)

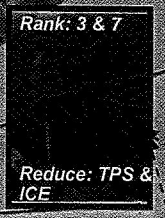


Thrust Strut Flange: OML Change (ET-125 & 128)

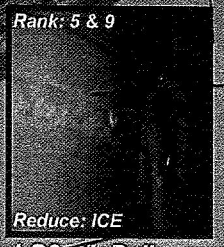


LO2 F/L & Flange Interference (ET-130)

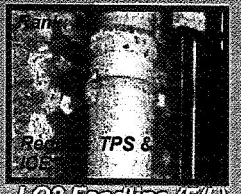
Aft GH2 Press line Fairing (ET-135)



LO2 F/L Strut (ET-125 & 128)

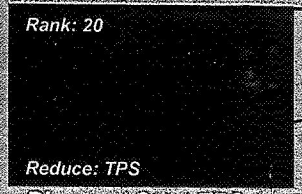


LO2 F/L Bellows Heaters (ET-128)



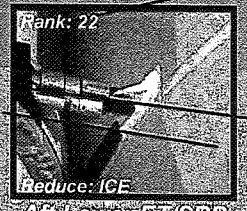
LO2 Feedline (F/L) Base closeout (ET-128)

Diagonal Strut Closeout (ET-117)



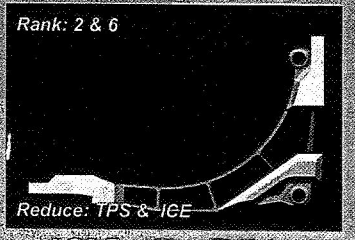
Diagonal Strut TPS (ET-133)

Umbilical Cable Trays (ET-131)



Aft Lower ET/SRB Fittings (ET-134)

Helium Inject Box TPS (ET-134)



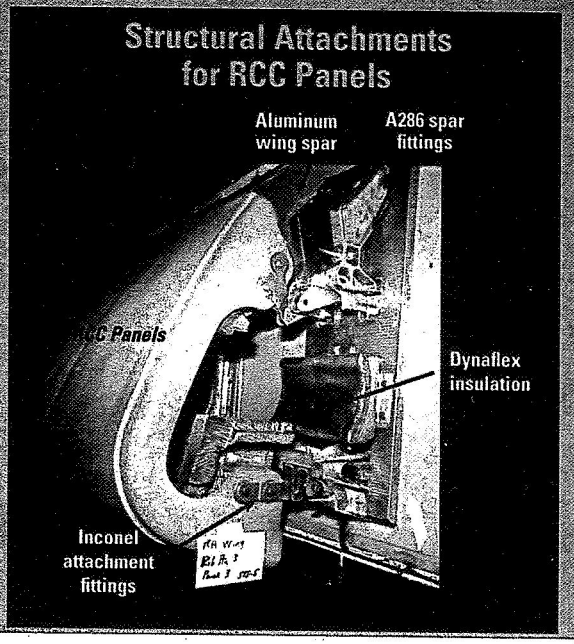
LO2 Feedline TI Yoke (ET-125 & 128)

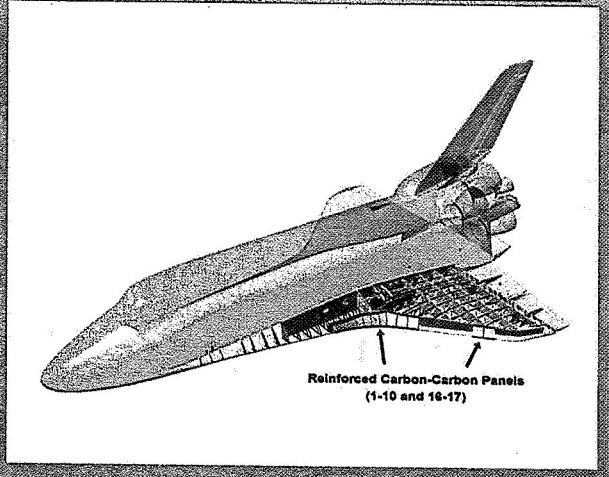
Ranking and ET Implementation based on SDS 6123

Several significant redesign initiatives have already been identified and prioritized.

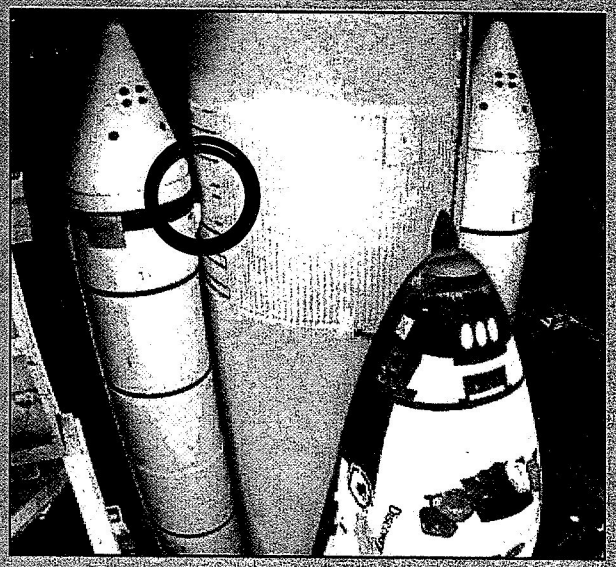
RCC nondestructive evaluation and TPS repair

- Removed all nosecap, chin panel, and wing leading edge RCC panels from each Orbiter.
- Returned to the manufacturer for evaluation.
- Testing methods included same evaluations done during the original acceptance testing, as well as new technologies developed since then.
- Still working on repair capability for TPS tile and RCC panels.
- Each technique must be tested and verified.
- Not considered sufficiently mature to be practicable for remaining Shuttle flights.



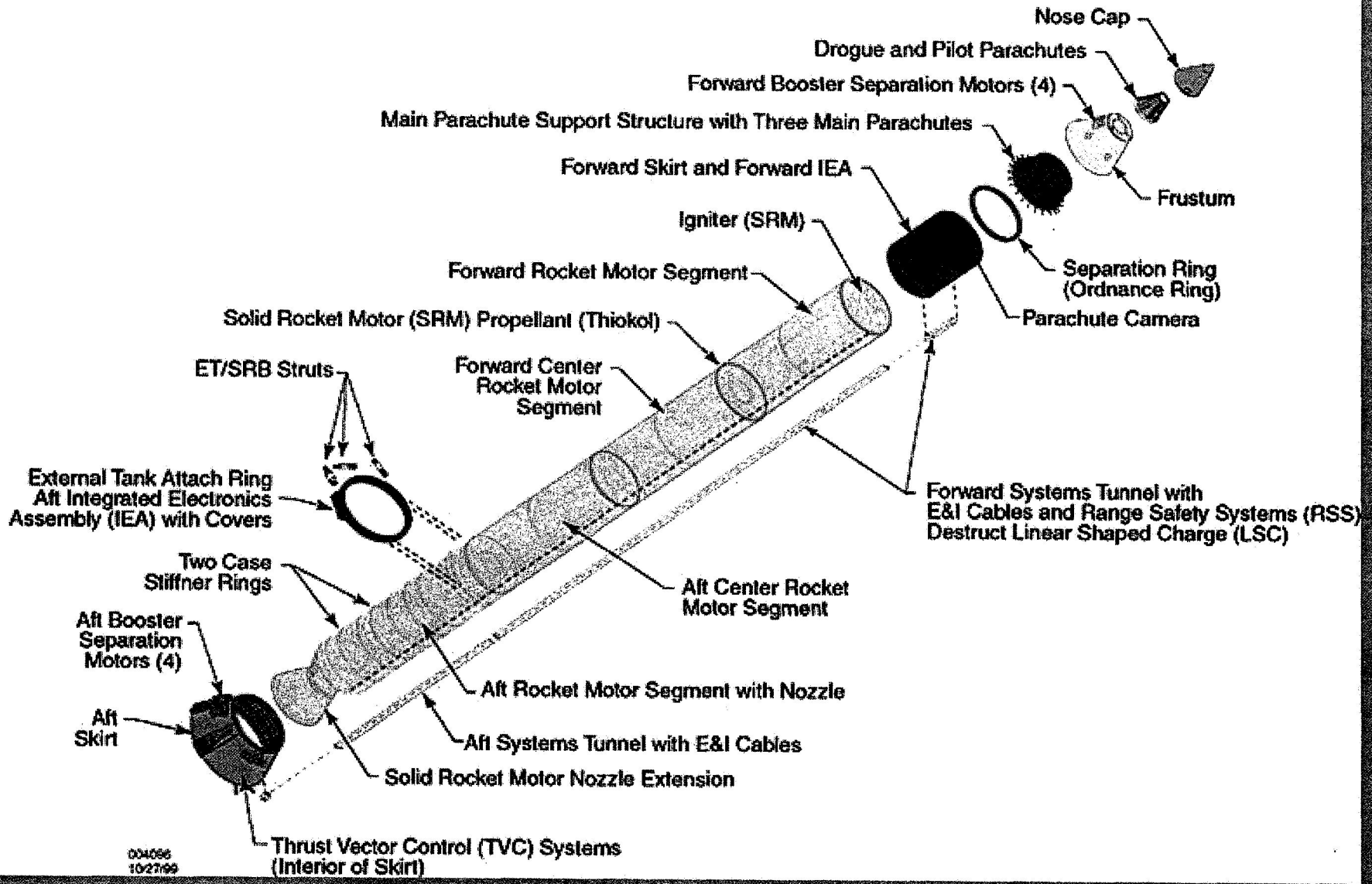


SRB bolt catcher



- Original design load did not include dynamic effects on energy absorber crush strength.
- Possible debris sources included SLA-561 thermal protection material, attach fasteners, or insert failure.
- New design uses cork as TPS material and has passed factor of safety testing.

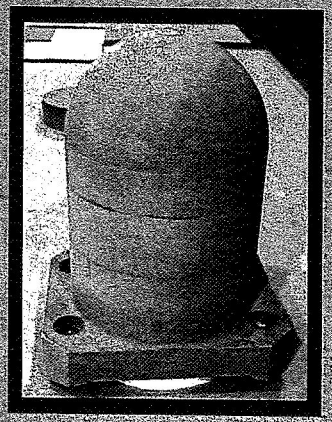
SRB Schematic

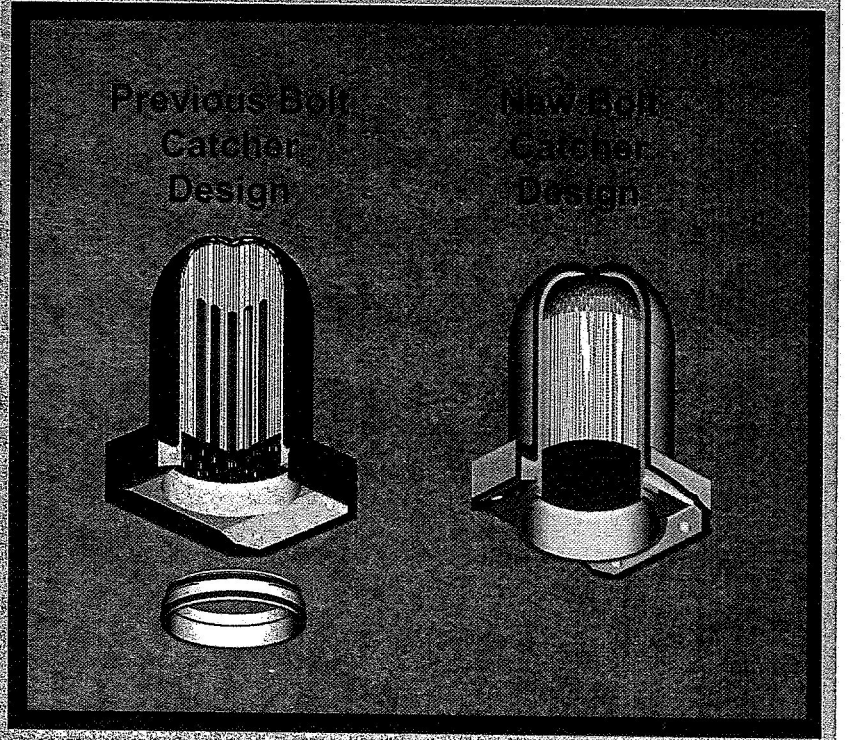


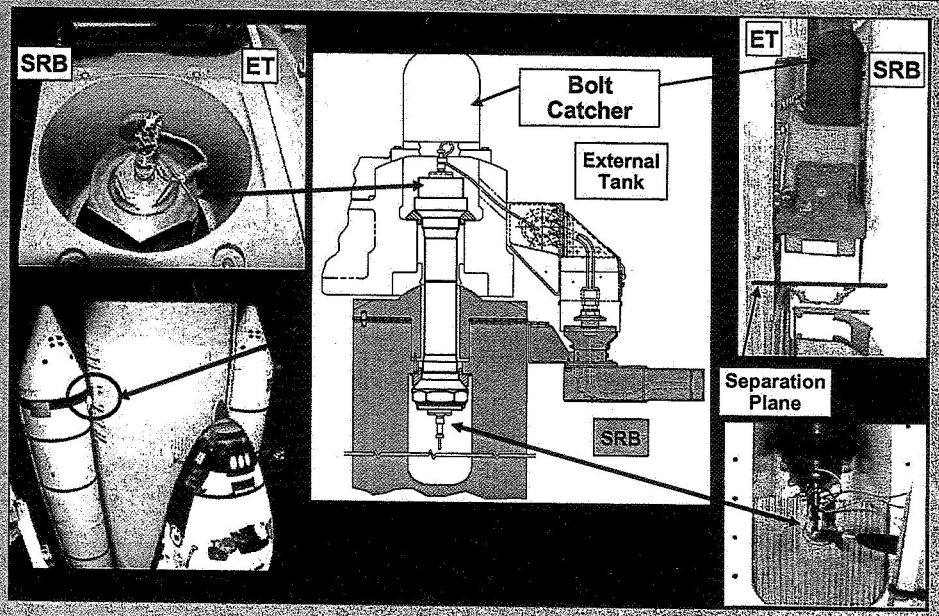
SRB Return to Flight

Bolt Catcher NSIPC Redesign

- Bolt catcher redesigned to increase margin of safety
- NSI pressure cartridge redesigned to eliminate NSI ejection





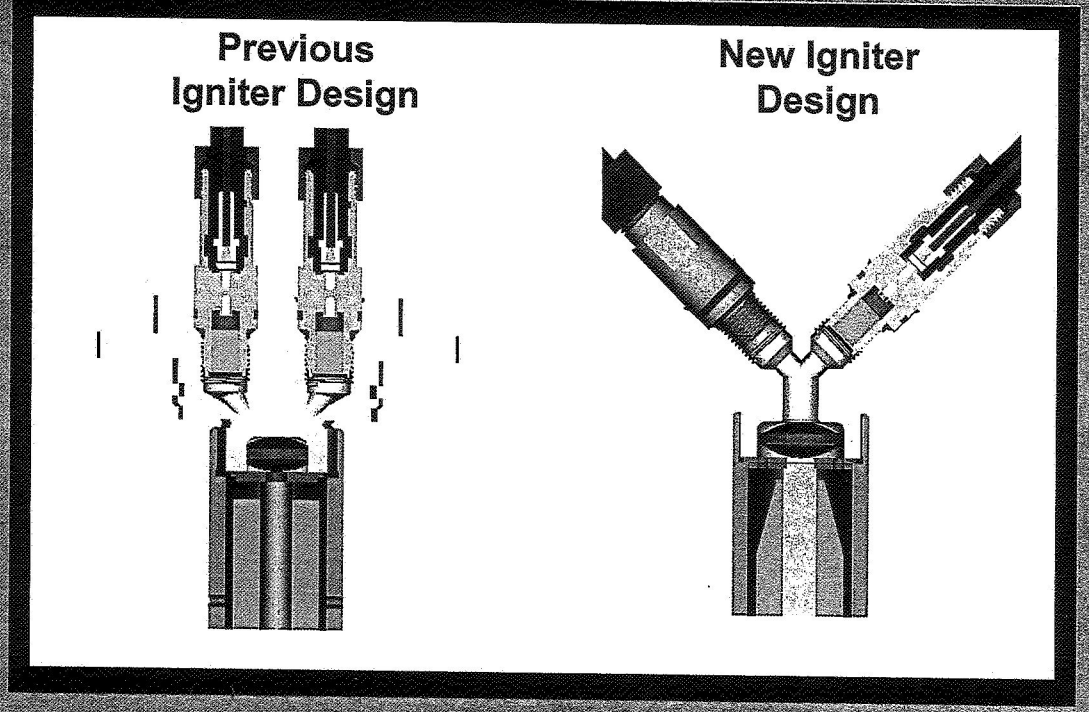


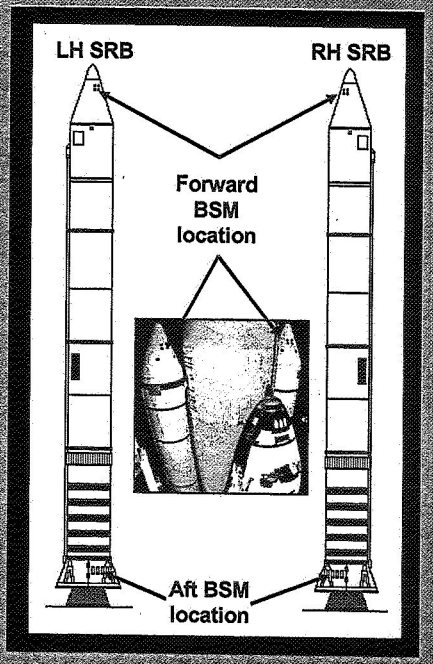
Play Video
Bolt Catcher

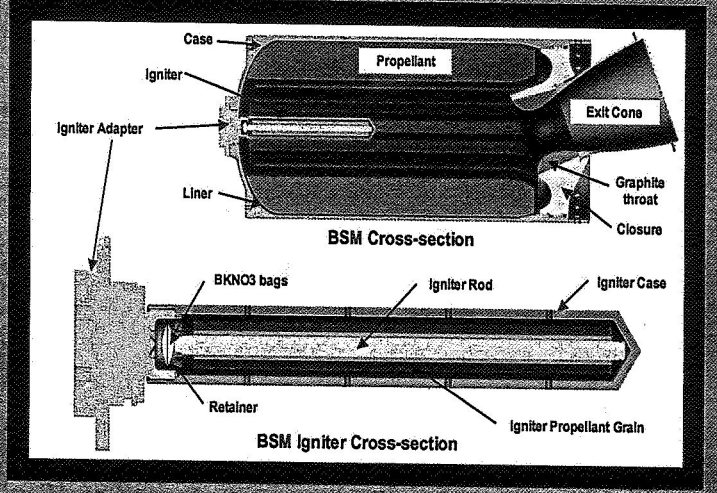
Play Video
Fwd. Sep Firing

SRB Return to Flight

Booster Separation Motor (BSM) Igniter Redesign



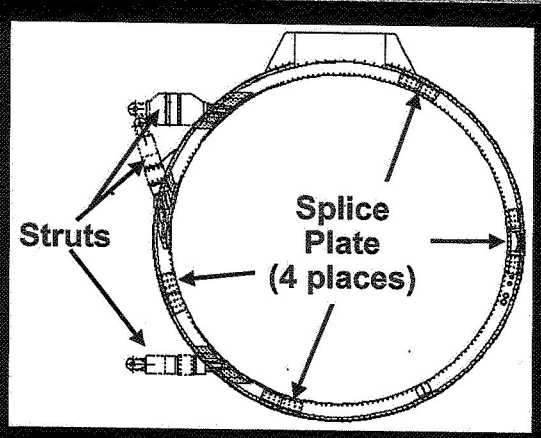




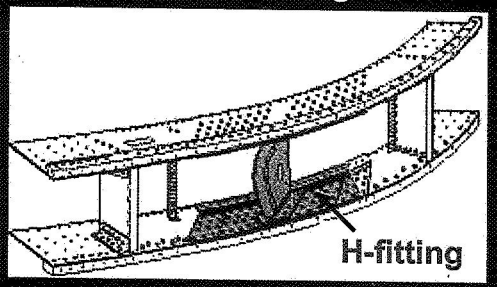
- Booster Separation Motor Igniter redesigned to eliminate erratic performance

SRB Return to Flight

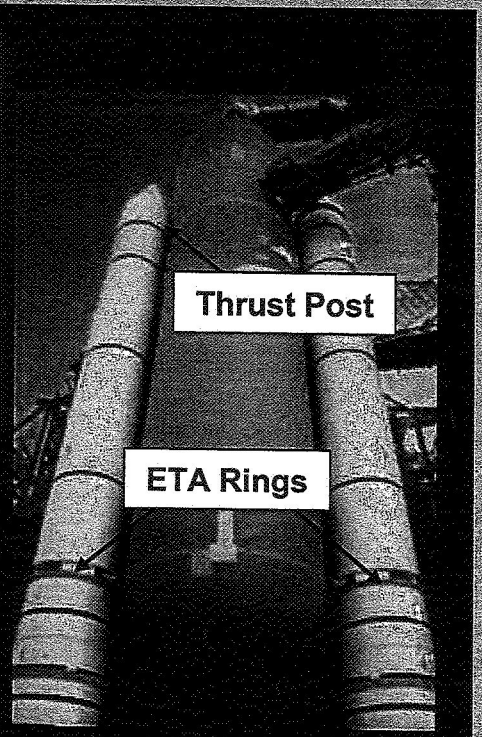
External Tank Attach (ETA) Ring



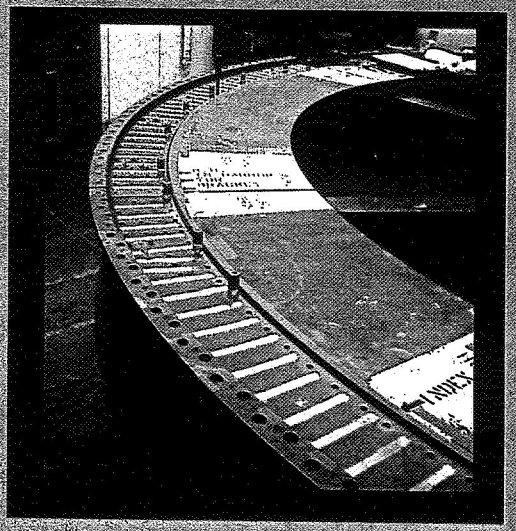
LH ETA Rings



Ring Segment



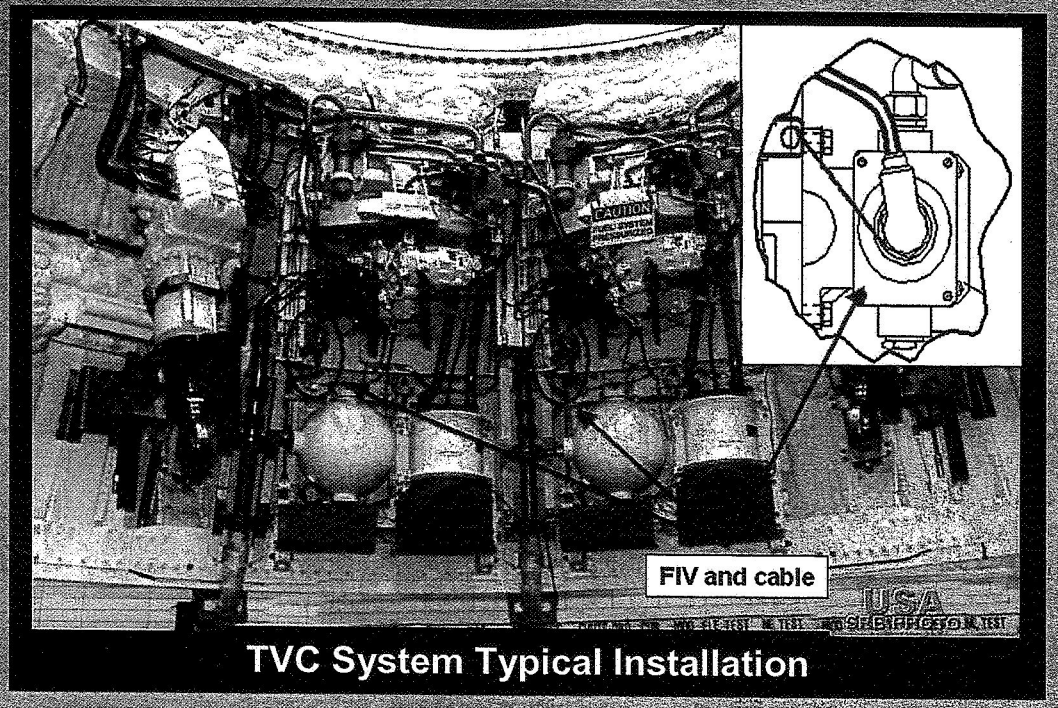
Location of ETA Rings



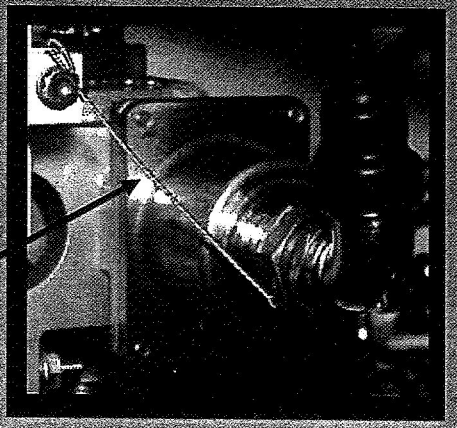
- Implement 4340 Steel ETA Ring

SRB Return to Flight

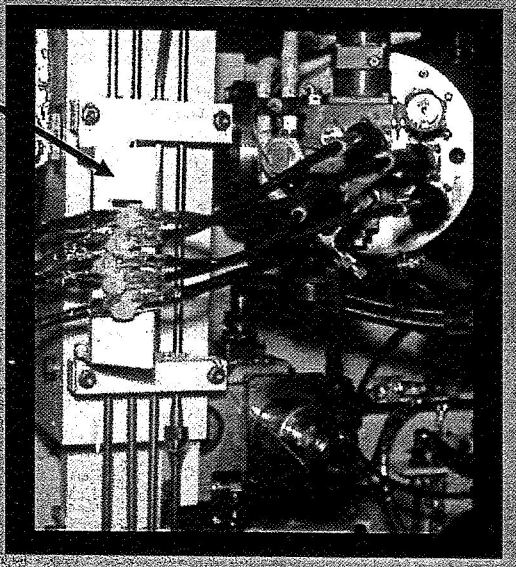
Fuel Isolation Valve (FIV) Connector and Backshell



TVC System Typical Installation



Safety Wire



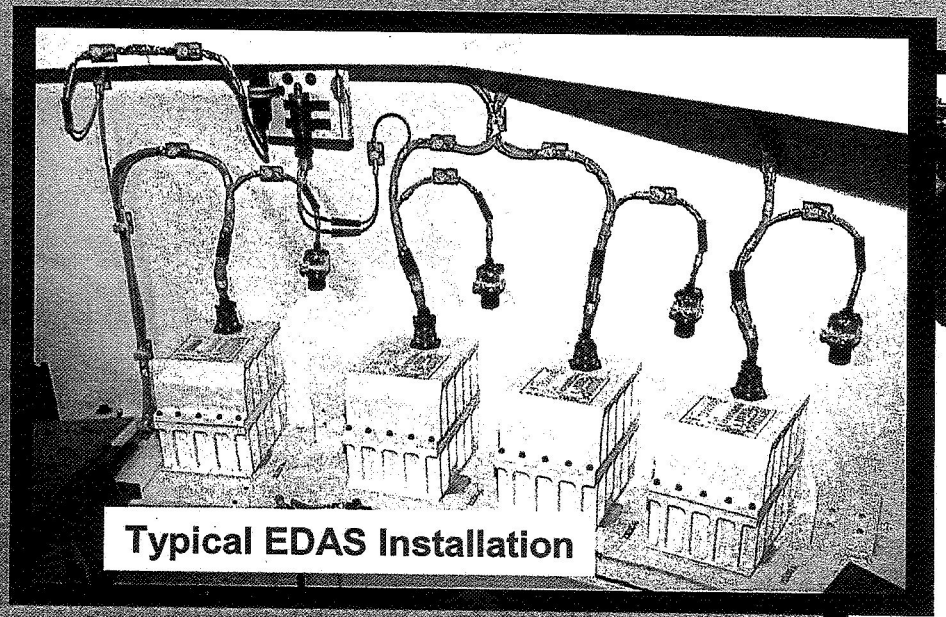
Support Bracket

- Enhanced cable securing
  - New bracket added to installation
  - Reduces length for unsupported cable
  - Lockwire replaced Loctite on connector threads

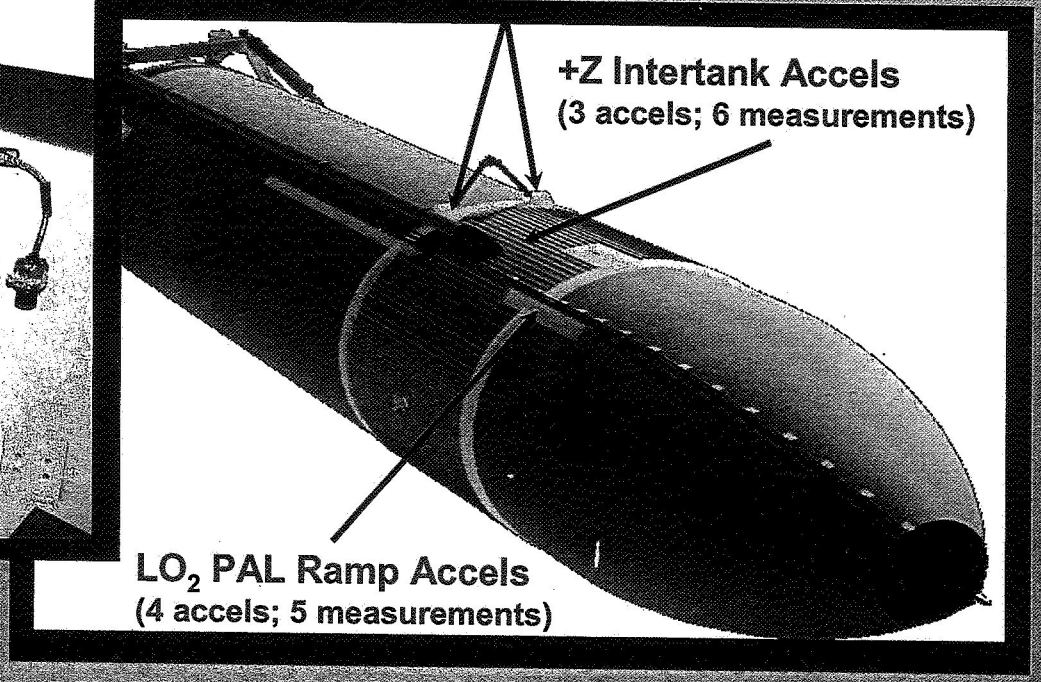
SRB Return to Flight

External Tank Instrumentation

- Enhanced Data Acquisition System (EDAS) used to record 13 ET measurements

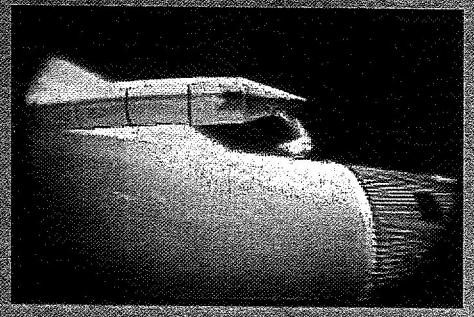


Typical EDAS Installation

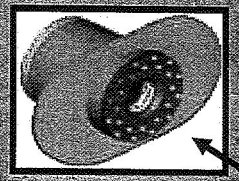


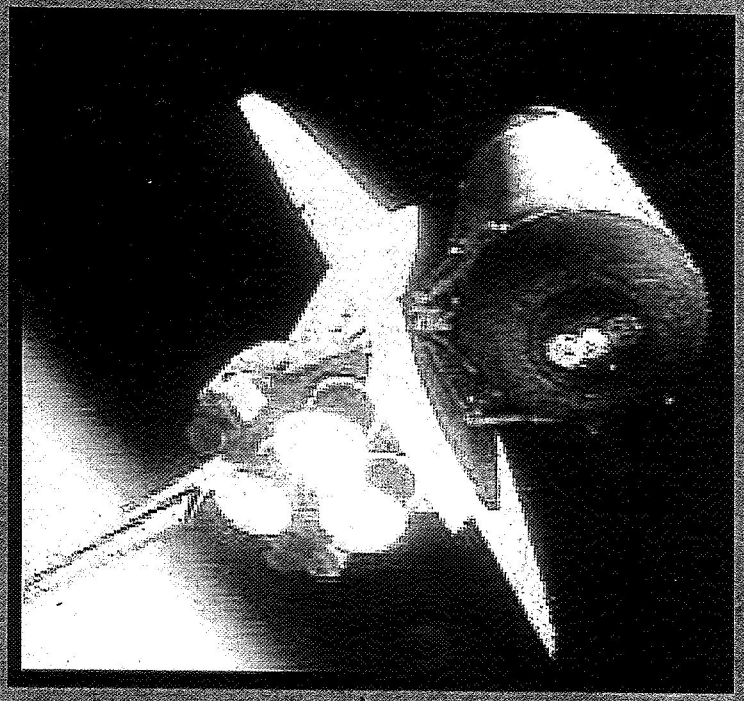
SRB Return to Flight

SRB Camera System

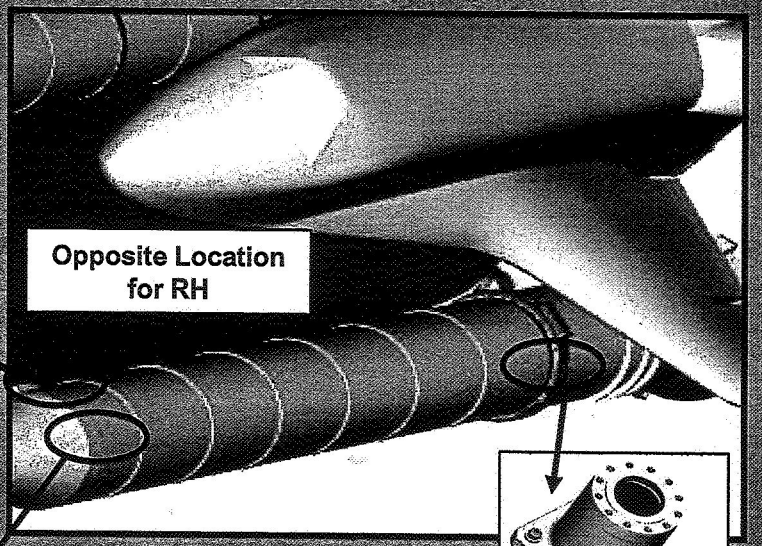


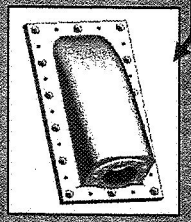
ET Observation Camera



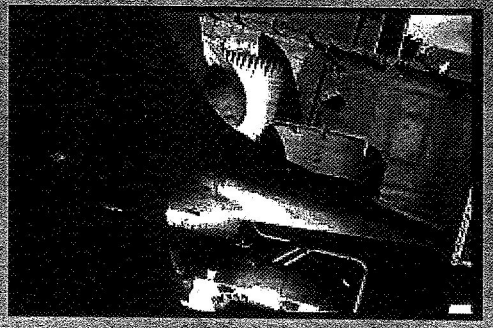


Play Video

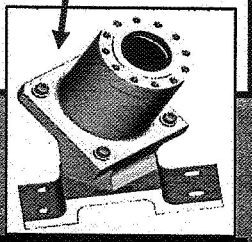


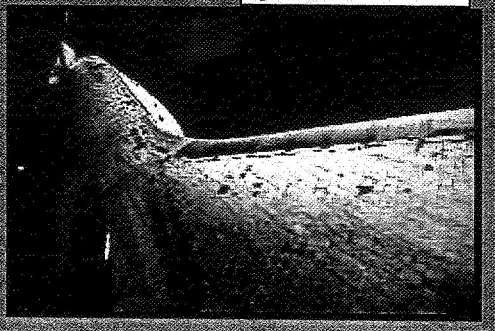


Forward Skirt Camera



ETA Ring Camera



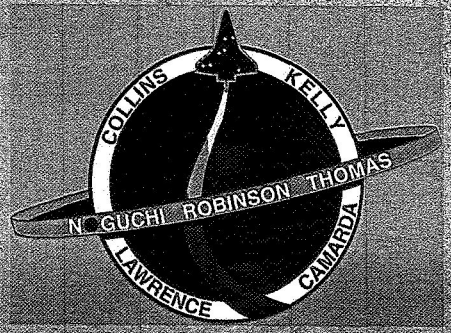


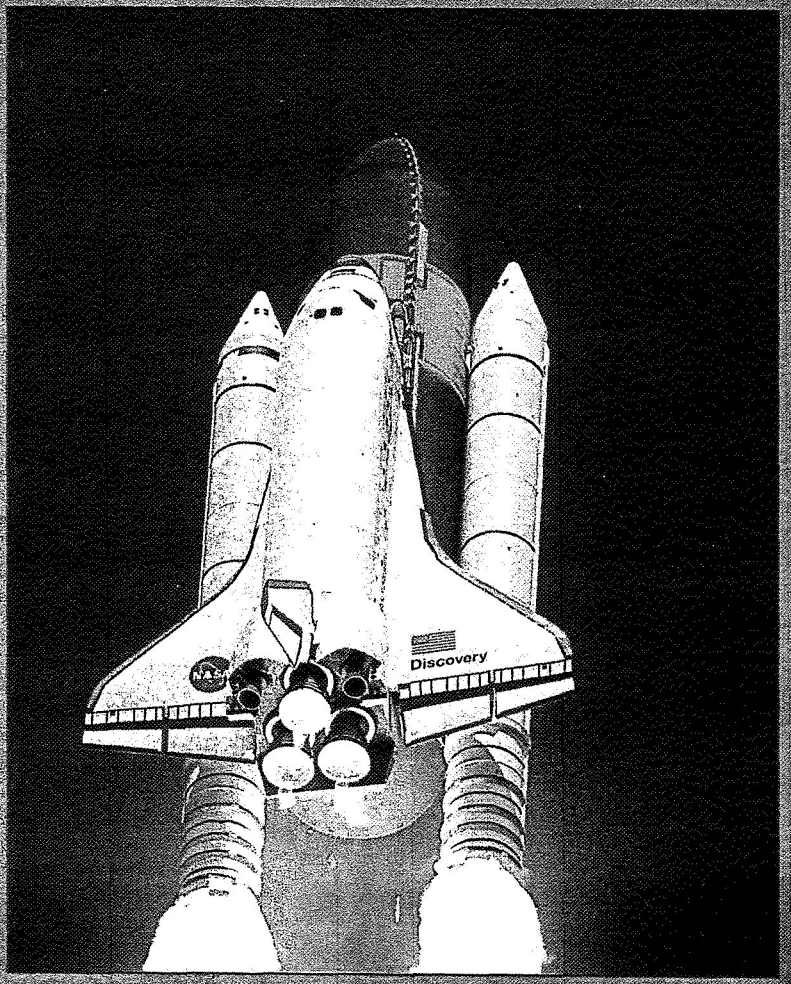
Return to Flight: *Discovery*

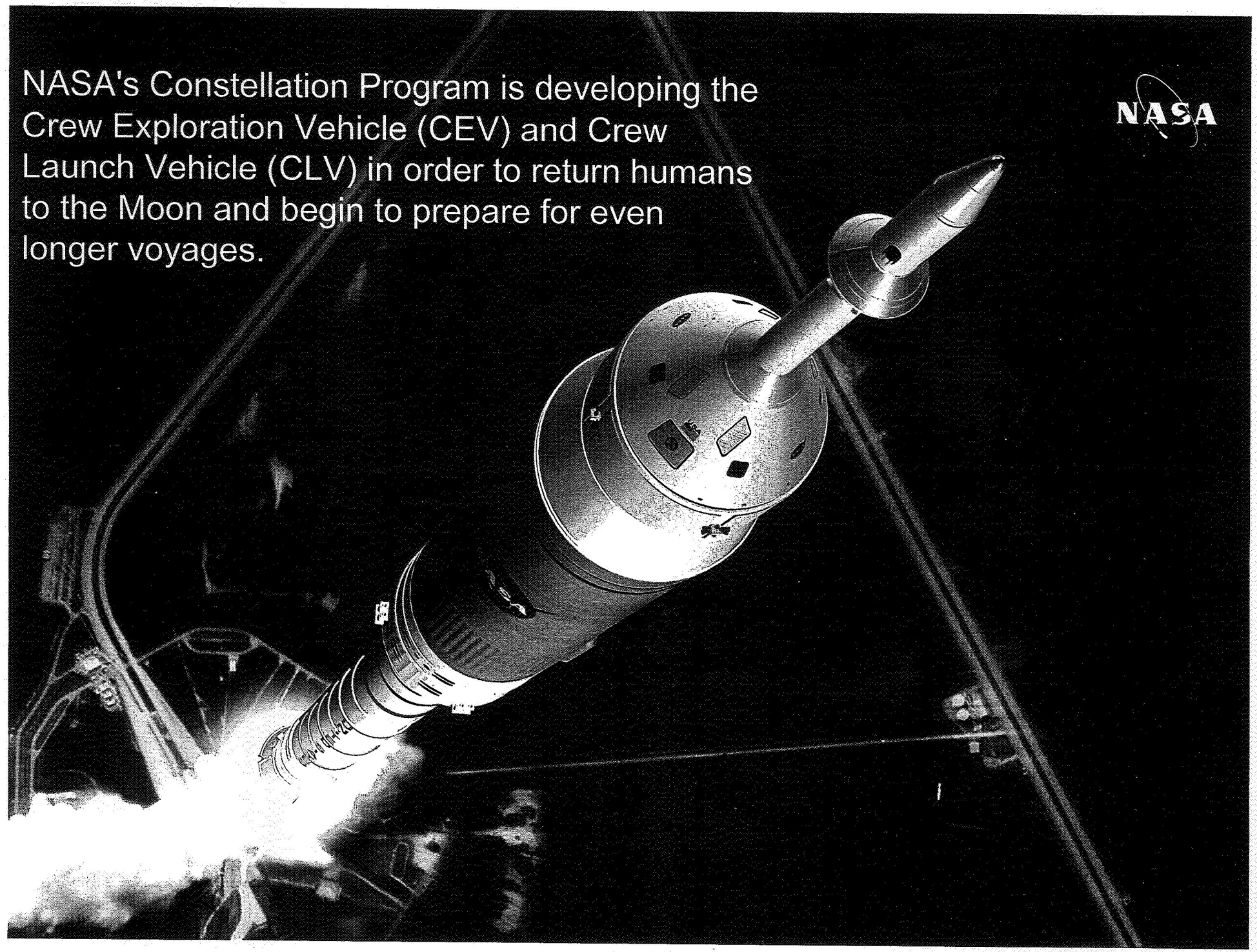
On July 26, 2005, Space Shuttle *Discovery* was launched during STS-114.

Two weeks later, the mission concluded with a successful landing at Edwards AFB, CA.

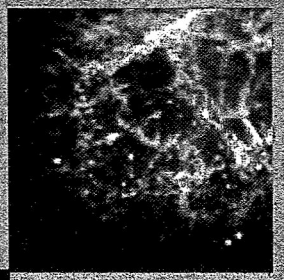
Continued with STS-115.






NASA's Constellation Program is developing the Crew Exploration Vehicle (CEV) and Crew Launch Vehicle (CLV) in order to return humans to the Moon and begin to prepare for even longer voyages.
NASA

Questions and Answers



www.nasa.gov/centers/marshall